Photon-Counting Kinetic Inductance Detectors for the Origins Space Telescope

Completed Technology Project (2017 - 2020)

Project Introduction

We propose to develop photon-counting Kinetic Inductance Detectors (KIDs) for the Origins Space Telescope (OST) and any predecessor missions, with the goal of producing background-limited photon-counting sensitivity, and with a preliminary technology demonstration in time to inform the Decadal Survey planning process. The OST, a mid- to far- infrared observatory concept, is being developed as a major NASA mission to be considered by the next Decadal Survey with support from NASA Headquarters. The objective of such a facility is to allow rapid spectroscopic surveys of the high redshift universe at 420-800 μm, using arrays of integrated spectrometers with moderate resolutions ($R=\lambda/\Delta\lambda \sim 1000$), to create a powerful new data set for exploring galaxy evolution and the growth of structure in the Universe. A second objective of OST is to perform higher resolution ($R\sim$10,000-100,000) spectroscopic surveys at 20-300 μm, a uniquely powerful tool for exploring the evolution of protoplanetary disks into fledgling solar systems. Finally the OST aims to obtain sensitive mid-infrared (5-40 μm) spectroscopy of thermal emission from rocky planets in the habitable zone using the transit method. These OST science objectives are very exciting and represent a well-organized community agreement. However, they are all impossible to reach without new detector technology, and the OST can't be recommended or approved if suitable detectors do not exist. In all of the above instrument concepts, photon-counting direct detectors are mission-enabling and essential for reaching the sensitivity permitted by the cryogenic Origins Space Telescope and the performance required for its important science programs. Our group has developed an innovative design for an optically-coupled KID that can reach the photon-counting sensitivity required by the ambitious science goals of the OST mission. A KID is a planar microwave resonator patterned from a superconducting thin film, which responds to incident photons with a change in its resonance frequency and dissipation. This detector response is intrinsically frequency multiplexed, and consequently KIDs at different resonance frequencies can be read out using standard digital radio techniques, which enables multiplexing of ~10,000s of detectors. In our photon-counting KID design we employ a small-volume (and thin) superconducting Al inductor to enhance the per-photon responsivity, and large parallel-plate NbTiN capacitors on single-crystal silicon-on-insulator (SOI) substrates to eliminate frequency noise. We have developed a comprehensive design demonstrating that photon-counting sensitivity is possible in a small-volume Al KID. In addition, we have already demonstrated ultra-high quality factors in resonators made of very thin (~10 nm) Al films with long electron lifetimes. These are the critical material parameters for reaching photon-counting sensitivity levels. In our proposed work plan our objective is to implement these high quality films into our optically-coupled small-volume KID design and demonstrate photon-counting sensitivity. The successful development of our photon-counting technology will significantly increase the sensitivity of the OST mission, making it more scientifically competitive than one based on power detectors. Photon-counting at the background limit provides a x4

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Organizational Responsibility

Responsible Mission Directorate:

Science Mission Directorate (SMD)

Lead Organization:

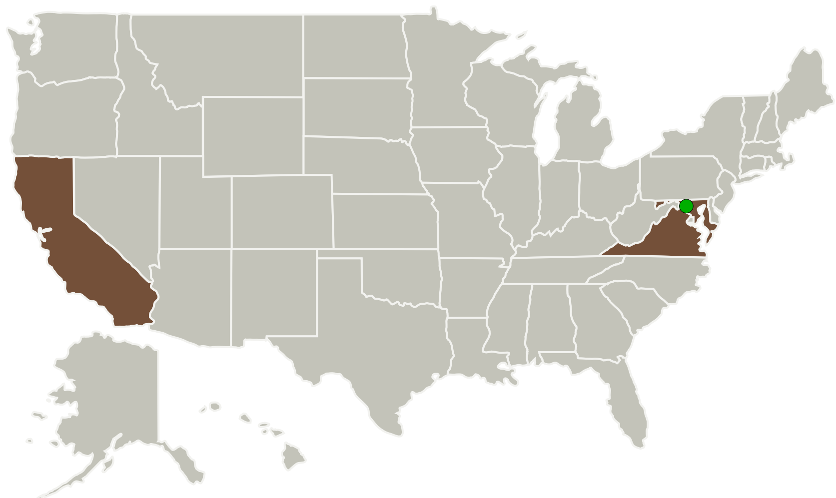
Associated Universities, Inc.

Responsible Program:

Astrophysics Research and Analysis

increase in observation speed over that of background-limited power detection, since there is no need to measure and subtract a zero point. Photon-counting detectors will enable an instrument on the OST to observe the fine structure lines of galaxies which are currently only observable at redshifts of z~1, out to redshifts of z=6, probing the early stages of galaxy, star and planet formation. Our photon-counting detectors will also enable entirely new science, including the mapping of the composition and evolution of water and other key volatiles in planet-forming materials around large samples of nearby young stars.

Primary U.S. Work Locations and Key Partners



Project Management

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Technology Areas

Primary:

- TX08 Sensors and Instruments
  └ TX08.1 Remote Sensing Instruments/Sensors
    └ TX08.1.1 Detectors and Focal Planes

Target Destination

Outside the Solar System

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Organizations Performing Work	Role	Type	Location
Associated Universities, Inc.	Lead Organization	Industry	Charlottesville, Virginia
Goddard Space Flight Center(GSFC)	Supporting Organization	NASA Center	Greenbelt, Maryland
National Radio Astronomy Observatory	Supporting Organization	R&D Center	Charlottesville, Virginia
Space Telescope Science Institute(STScI)	Supporting Organization	Academia	Baltimore, Maryland
SRON, Netherlands Institute for Space Research	Supporting Organization	Academia	Utrecht, Outside the United States, Netherlands
University of California-Berkeley(Berkeley)	Supporting Organization	Academia	Berkeley, California
University of Virginia-Main Campus	Supporting Organization	Academia	Charlottesville, Virginia

Primary U.S. Work Locations	
California	Maryland
Virginia	